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Website: www.aarf.asia Email : editor@aarf.asia , editoraarf@gmail.com

SEASONAL VARIATION IN SOIL CO_2 FLUX IN SUB-TROPICAL FOREST ECOSYSTEM WITH FLUCTUATING ABIOTIC VARIABLES.

M.Dineswori Devi and Asha Gupta
Ecology Laboratory, Department of Life Sciences
Centre of Advanced study in Life Sciences, Manipur University,
Canchipur Imphal 795003, India

ABSTRACT

The temporal and seasonal variation in soil CO2 flux in sub-tropical forests of Manipur, N.E. India was determined in relation to the changes in abiotic variables viz. soil temperature and soil water content.The soil CO_2 flux rate shows significant positive co-relation with abiotic factors viz., soil moisture and soil temperature.The variability in soil CO_2 flux was recorded to be 88.1% and 82.0% due to soil temperature and soil moisture respectively in forest stand I and 88.3% and 72.4% due to soil moisture and soil temperature respectively in forest stand II.The soil CO_2 flux ranged from 67.69 to 382.35mg$CO_2$$m^{-2}hr^{-1}$ and 74.60 to 394.88mg$CO_2$$m^{-2}hr^{-1}$ for forest stands I and II respectively in different months throughout the year. Maximum soil CO_2 flux rate was observed during rainy season and minimum during winter season.

Keywords: Soil CO_2 flux, abiotic variables, Multiple Regression, Seasonal Variation, N.E. India.

Introduction:

Human activities such as burning of fossil fuels and land use have led to the increase of CO_2 in the atmosphere resulting into the warming up of the earth and affecting the climate. Atmospheric carbon dioxide has increased from 280 ppm in the preindustrial era to 390 ppm in 2011 (WMO, 2012). In the study of climate change and carbon cycling interaction, there are two main natural carbons sinks namely the ocean and terrestrial biosphere that have absorbed nearly half of all artificial carbon dioxide emissions (Zheng *et. al*., 2013). Soil is a major carbon (C) reserve in terrestrial ecosystems (Adachi *et. al*., 2009). Soil contains 2700Gt of Carbon. This amount is more than the sum of carbon in atmosphere (780Gt) and biomass (575Gt) as per Lal (2008). Carbon dioxide is released from the soil through soil respiration which involves three biological processes namely faunal respiration, microbial respiration and root respiration. Root respiration is one of the main fluxes in the global carbon cycle as soil is a major carbon reserve in the terrestrial ecosystems. Since soil respiration is directly related to both microbial and root activities, its temporal and spatial variations are largely controlled by environmental factors such as precipitation, soil moisture and temperature (Hanpattanakit *et. al*., 2009). The soil microbial communities are generally related to the soil organic matter (Wu *et. al*., 2015), soil nutrients (Allison and Maitiny, 2008), and other properties such as pH and soil texture (Lauber *et. al*., 2009; Carson *et. al*., 2010). The seasonal variability of soil CO_2 flux is greatly explained by soil temperature and soil water content. A primary source of variability of soil CO_2efflux is temporal heterogeneity. Accordingly, soil CO_2 efflux is known to exhibit a diurnal cycle, due in part to a diurnal soil temperature cycle (Shi *et. al*.,2012) Seasonal changes in soil microclimate play a key role in defining seasonal differences in soil carbon dioxide emission within sites and climatic differences generate different soil respiration rates among distant sites (Raich and Potter, 1995).Chen *et. al*., 2015 haveshown correlation among the spatial variations in the climate, vegetation, soil factors and ecosystem CO_2 fluxes.

For the present study two forest stands situated at Sauntak Molnom at $25^0$03'N latitude and $93^0$55'E longitude at an altitude of 988 m above mean sea level (Stand-I) and Stand-II located at $24^0$55'N latitude and $93^0$48'E longitude at an altitude of 1294 m above mean sea level at Konshram Konshakhul in Senapati district of Manipur, N.E. India were earmarked. The climate of the area is monsoonic with warm moist summer and cool dry winter. The mean maximum temperature varied from 21.83^0C (January) to 29.68^0C (August) and mean minimum temperature ranged from 5.04^0C (January) to 22.33^0C (July). The mean annual rainfall is 1428.49 mm. The average relative humidity of air varied between 62.94% (March) to 82.76% (July). The study was conducted during the 2011-2012. Soils of the study area were sandy loam in texture and reddish in colour in forests stand I and blackish brown in forest stand II. Forest stand I is dominated by *Quercus serrata* and *Schima wallichii* and is situated at the base of the hill. Forest stand II is dominated by *Ficus virens* and *Cinnamomum zeylanicum*.

Materials and Methods

Soil samples were collected from the two study sites randomly at monthly intervals from April 2011 to March 2012 for the analysis of soil physico-chemical characteristics. Soil bulk density is weight of oven dry soil per unit volume which is usually expressed in gcm^3.Soil pH was determined by (1:5; soil water suspension) by a pH meter (Systronics). The soil texture was analysed by International pipette method of mechanical analysis (Gee and Bauder 1986). The soil organic carbon was estimated by Walkley- Black method. Total soil nitrogen was measured using 2100 Kjeltec system and available soil phosphorus was determined following the method given by Bray and Kurtz (1945).Soil CO_2 emission was measured by alkali absorption method using an open ended aluminium cylinder (25cm tall and 13cm diameter) as per Anderson and Ingram (1993).Leaf litter were collected by laying down randomly 10 plots of $1m^2$ size quadrat in each forest sites on monthly interval.

Results and Discussion

The soil was sandy loam in texture in both the forest stand. In forest stand I 68.83% sand, 18.66% silt and 12.26% clay where as in forest stand II 72.63% sand, 16.6% silt and 10.6% clay was reported.Soil temperature varied from 13.36^0C to 22.68^0C in stand I and 11.34^0C to 21.36^0C in stand II. Soil pH ranged from 4.35 to 4.71 and 5.17 to 5.57 in forest stand I and II respectively. Soil moisture varied from 19.88% to 46.76% and 17.98% to 36.89% in forest stand I&II respectively.

Table 1: Abiotic variables of soils in forest stand I and stand II.

Abiotic variables	Stand-I	Stand-II
Soil temperature(0C)	18.92	17.59
Soil Moisture (%)	31.58	28.515
Soil texture	Sandy loam	Sandy loam
Sand (%)	68.83	72.73
Silt (%)	18.66	16.66
Clay (%)	12.26	10.66
Bulk Density(gcm-3)	1.279	1.33
Soil pH	4.8-5.16	5.17-5.57
Organic Carbon(%)	1.41	1.56
Total Nitrogen (%)	0.277	0.305
Available Phosphorus(%)	0.03	0.051
C/N Ratio	5.31	5.13

Litter fall rate varies from 23.58gm^{-2} (July) to 138gm^{-2} (February) and 28.7gm^{-2} (August) to 137.08gm^{-2} (February) in sites I and II respectively. The total litter fall rate was recorded to be 7.89t ha^{-1} yr^{-1} for site I and 7.49t ha^{-1} yr^{-1} for site II as shown in Fig 1. The litter fall rate was found to be maximum in the month of February in both the forest stands. Then the rate of litter fall decreased consistently upto July in stand I leading to minimum litter fall which then increased thereafter. In forest stand II the minimum litter fall was observed in the month of August which thereafter increased until become maximum. The difference in the two stands might be due to difference in species composition.

The soil CO_2 flux ranged from 67.69 to 382.35 mgCO_2m^{-2}hr^{-1} and 74.60 to 394.88 mgCO_2m^{-2}hr^{-1}in forest stands I and II respectively. Maximum CO_2 flux rate were recorded in the month of August in both the forest stands which then decreased consistently till January and thereafter increased (Fig 2). Seasonally, the mean CO_2 flux rate was recorded maximum during rainy season followed by summer season and winter season. The soil CO_2 flux rate correlated positively and significantly with abiotic factors viz., soil moisture, soil temperature, relative humidity, mean air temperature and rainfall in both the forest stands I and II (Table3). The variability in soil CO_2 flux was recorded to be 88.1% and 82.0% due to soil temperature and soil moisture respectively in forest stand I and 88.3% and 72.4% due to soil moisture and soil temperature respectively in forest stand II.

The relationship between rate of soil CO_2 flux (mgCO_2m^{-2}hr^{-1}) and soil properties, i.e. soil temperature (X_1), soil moisture (X_2) and soil organic carbon (X_3) has been analysed by multiple regression in both the study sites and is summarized as follows:

Site-I

$$Y= -655.568 + 11.29X_1 + 2.804X_2 + 402.179X_3,$$

($r_1 = 0.93$; $r_2 = 0.90$; $r_3 = 0.52$) at $P< 0.05$.

Site-II

$$Y= -794.313 + 3.892X_1 +3.116X_2 + 532.890X_3,$$

($r_1 = 0.85$; $r_2 = 0.93$; $r_3 = 0.51$) at $P< 0.05$.

The study shows that there is significant positive relationship between soil CO_2 flux rates and abiotic variables. Soil moisture, soil temperature and soil organic carbon has strong influence on the release of CO_2 into the atmosphere from the soil in both the ecosystems. Similar findings have also been reported in different ecosystems by several workers.

Table 2. Annual soil CO_2 flux (g CO_2 m^{-2} $year^{-1}$) in the two forest stands

Site	Annual soil CO2 flux
Stand I	1929.48
Stand II	1877.86

Table 3. Annual organic carbon input as litter fall (g C m^{-2} $year^{-1}$) and soil CO_2 flux rate as output (g C m^{-2} $year^{-1}$) in the two forest stands.

Site	Input	Output
Stand I	424.21	525.12
Stand II	374.83	511.51

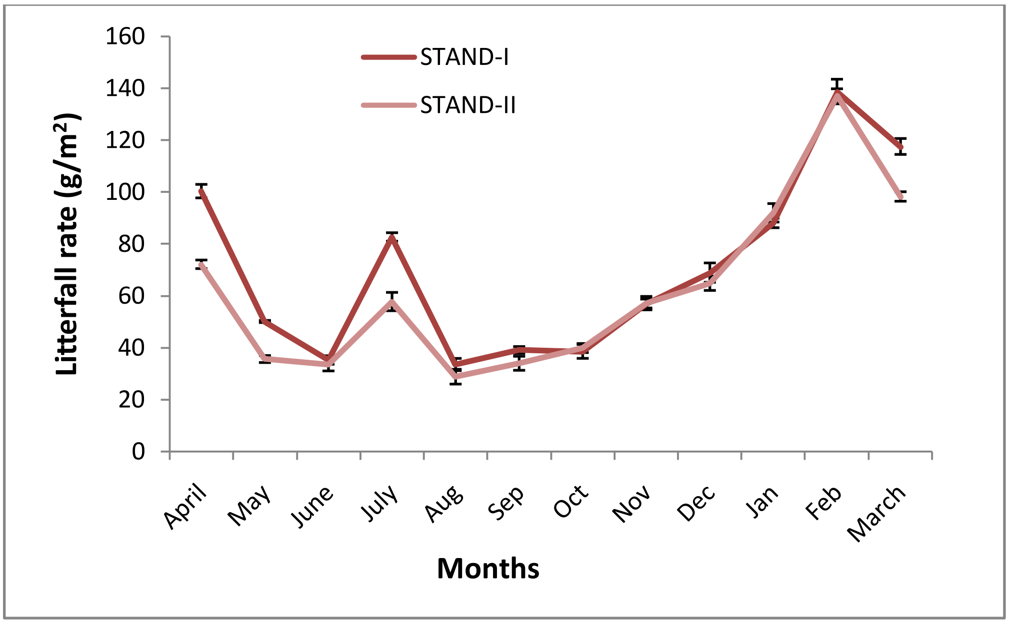

Fig. 1 Monthly variation of litter fall rate in Forest stand-I and Forest stand-II.

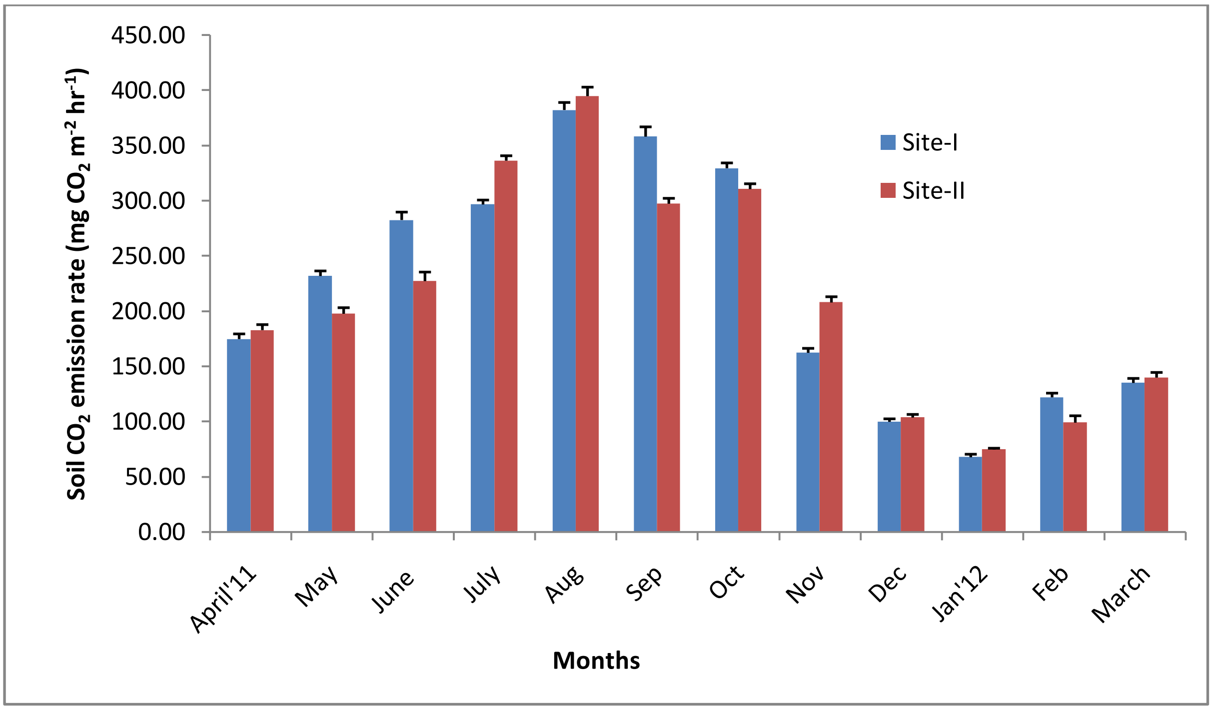

Fig.2. Monthly variation of soil CO_2 emission rate (mg CO_2 m^{-2} hr^{-1}) in Forest stand-I and Forest stand

Table 4: Seasonal variation in soil CO_2 emission rate (mg CO_2 m^{-2} hr^{-1}) in Forest stand-I and Forest stand-II.

Season	Stand I	Stand II
Summer (March – May)	180.58	173.5
Rainy (June – October)	392.9	313.32
Winter(November-February)	112.96	121.32
Mean Annual	220.26	214.37

Table 5: ANOVA of Soil CO_2 emission rate in forest stand I

Sources of variation	SS	df	MSS	F	P
Summer					
Between the months	23705.824	2	11852.912	118.981	P<0.01
Within the months	1195.443	12	99.620		
Total	24901.267	14			
Rainy					
Between the months	34416.474	4	8604.119	40.093	P<0.01
Within the months	4292.075	20	214.604		
Total	38708.549	24			

Winter					
Between the months	23705.638	3	7901.879	138.901	P<0.01
Within the months	910.218	16	56.889		
Total	24615.856	19			
Annual					
Between the months	636235.40	11	57839.582	433.950	P<0.01
Within the months	6397.735	48	133.286		
Total	642633.134	59			

Table 6: ANOVA of Soil CO_2 emission rate in forest stand II

Sources of variation	SS	df	MSS	F	P
Summer					
Between the months	9023.431	2	4511.715	35.326	P<0.01
Within the months	1532.618	12	127.718		
Total	10556.049	14			
Rainy					
Between the months	72843.409	4	18210.852	90.154	P<0.01
Within the months	4039.930	20	201.996		
Total	38708.549	24			
Winter					
Between the months	52453.490	3	17484.497	185.292	P<0.01
Within the months	1509.792	16	94.362		
Total	53963.282	19			
Annual					
Between the months	578759.127	11	52614.466	357.286	P<0.01
Within the months	7068.550	48	147.261		
Total	585827.677	59			

Table 7: Correlation coefficient (r) for the relationship of soil CO_2 emission rate with the abiotic variables measured in the two forest stands.

Parameters	Stand I	Stand II
Soil moisture (%)	0.829	0.871
Soil Temperature (^{0}C)	0.938	0.850
Relative Humidity (%)	0.828	0.798
Mean Air Temperature (^{0}C)	0.880	0.825
Rainfall	0.647	0.586

NS- not significant; $P<0.05$

Table8: Soil CO_2 emission rate (mg CO_2 m^{-2} hr^{-1}) in different ecosystems of theworld

Sl. No.	Type of forest	Place	Rate	Author
1.	Primary forest	Malaysia	769	Adachi *et.al.*,2005
2.	Secondary forest	Malaysia	708	Adachi *et. al.*,2005
3.	Oil palm plantation	Malaysia	815	Adachi *et. al.*,2005
4.	Rubber plantation	Malaysia	450	Adachi *et. al.*,2005
5.	Tropical forest	Costa Rica	430-675	Schwedenmann *et. al.*,2003
6.	Tropical forest	Brazil	216-510	Fernandes *et. al.*,2002
7.	Dry Dipterocarpus forest	Thailand	200-700	Hanpattanakit *et. al.*,2009
8.	Sitka spruce forest	Ireland	699.2	Olajuyigbe *et. al.*,2012
9	*Pinus wallichiana* forest	India	182-646	Sundarapandian *et. al.*,2013
10	*Abies pindrow* forest	India	126-427	Sundarapandian *et. al.*,2013
11.	Sub tropical evergreen broad leaf forest	South China	477.9	Yi *et. al.*,2007
12.	Pine forest	South China	429.5	Yi *et. al.*,2007
13.	Pine and broad leaf mixed forest	South China	435.4	Yi *et. al.*,2007
14.	Mix oak forest	Manipur,India	138-250	Devi &Yadava 2006
15.	Natural mixed oak forest	Manipur,India	102-320	Pandey *et. al.*,2010
16.	Oak plantation	Manipur,India	99-543	Pandey *et. al.*,2010
17.	Mixed oak forest	Manipur,India	67.6-382.35	Present study
18.	Sub tropical mixed evergreen forest	Manipur,India	74.6-394.88	Present study

The soil CO_2 flux shows negative relationship with the litter fall in different months in both the forest stands. There is a significant high litter fall during the dry and cool winter season as compared to the rainy season. But on the contrary soil CO_2 emission is minimum during winter and maximum during rainy season. Thus this shows that monthly plant litter fall does not show any effect on soil CO_2 emission.

The rate of soil CO_2 flux was recorded to be maximum in the month of August in both the forest stands as the micro flora and micro fauna becomes active due to availability of higher soil moisture coupled with soil temperature. The decomposition of plant litter enhanced during this period thereby increasing the rate of soil CO_2 flux. The rate of soil CO_2 flux was recorded to be minimum in the month of January in both the forest stands which may be due to low moisture content of soil and temperature thereby inhibiting the microbial activity and decomposition (Devi and Yadava, 2006) thus leading to low carbon dioxide emission. Chen *et. al.,* (2012) also found precipitation as an important factor influencing inter-annual variability in soil CO_2 flux. Thereafter there is a consistent increase in the soil CO_2 flux till August which may be due to high temperature and soil moisture with the onset of summer season. The difference in the rate of soil CO_2 flux in the two forests stands may be due to the difference in the diversity of micro flora, micro fauna and tree species. The mean soil CO_2 emission rate was found to be higher in the forest stand I as compared to forest stand II which may be due to higher soil moisture and higher soil temperature thereby enhancing the rate of higher microbial activity. A maximum rate of soil CO_2 flux in either spring or early summer season has been reported by several workers (Davidson *et. al.,* 2002, Laishram *et. al.,* 2002, Rastogi *et. al.,* 2002). On the contrary to their findings, we found a maximum rate of soil respiration in rainy season. Similar trend has also been reported by Devi and Yadava, 2008 in a Subtropical Mixed Oak Forest of Manipur, Northeastern India. Several reports on high soil respiration rate in wet season also exist (Kursar 1989, in a lowland moist forest Panama; Rajvansi and Gupta 1986 in Tropical *Dalbergia sisoo* forest; Savage and Davidson 2001 in Harvard forest; Saraswathi *et. al.,* 2008, in a semi-arid soil of India; Shi *et. al.,* 2012 on black soil in North East China) which are in conformity with our observations. An increasein soil respiration rate immediately after the rainfall events have also been reported (Holt *et. al.,* 1990 and Law *et. al.,* 2001). In both the forest stands a high correlation shows that soil CO_2 emission is positively affected by soil moisture, soil temperature, relative humidity, mean air temperature and rainfall. However soil temperature and air temperature have strong influence on soil CO_2 flux in comparison to other factors i.e. by soil moisture, relative humidity, and rainfall in forest stand I. In forest stand II soil moisture and air temperature have strong influence on soil CO_2 flux as compared to other factors.

Annual soil CO_2emission was the cumulative soil CO_2 flux rate from daily mean monthly values (Table 2). Annual soil CO_2emission was higher in stand I than in stand II. Annual carbon input was estimated from the annual litterfall rate and annual carbon output were estimated from annual CO_2 flux rate (g C m^{-2} $year^{-1}$). The input and output values of CO_2 in the two forest stand shows that the output rate is higher than the input rate which may be due to root respiration, CO_2 emission by the root decomposition or underestimates of litter fall.

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